Prospects of Hybrid Systems on Agricultural Machinery

J. Karner, M. Baldinger, and B. Reichl

Abstract— **"Hybrid system" is an actual catchword and it has entered agricultural engineering. Many projects dealing with electric drives on agricultural machines have been presented in the recent years. Their advantages are exact controllability, speed variability and overload capability. So called agro-hybrid-structures can be derived from automotive-hybrid-systems. The functionality strongly depends on the structure of the system. The use of electric drives appears to be promising in dedicated applications, where infinitely variable hydrostatic drives can be replaced and new functionalities can be realized.**

This paper considers selected hybrid-structures and -functions on the example of a tractor. Furthermore the potential of electric drives from the view of European manufacturers of agricultural machinery is reported.

Index Terms— **agriculture, electric vehicles, hybrid power systems, power systems**

I. INTRODUCTION

THIS work deals with the potential of electric drives on agricultural machinery. Modern agricultural machines have to perform efficiently and in the most productive manner. Implements can be powered either by a traction force, mechanically by PTO or hydraulically. The maximum power can only be transferred mechanically, while the speed ratio is basically preset. Infinitely variable speeds on implements are mainly realized by hydraulic drives. Hydraulic power can be distributed quite easily on the machine, but suffers from poor efficiency in part load operating conditions.

Nowadays agricultural machines are mainly driven mechanically or hydraulically and are often equipped with electronic control systems. The use of electric drives appears to be promising in dedicated applications. Recent developments and improvements have increased their applicability in agricultural machinery. High efficiency, controllability and overload-capability are of certain interest. So fuel consumption can be reduced and some working procedures can be automated.

A purely battery driven tractor is infeasible. The requested energy for the working process has to be stored on the tractor. In consequence of the high energy density of diesel-fuel it is assumed that the diesel-engine will be used dominantly in the agricultural business during the next decades. Comparisons with regard to energy density can be found e.g. in [1]–[3]. The specific energy is relevant to maximize operation range or duration. Therefore it is a measure for the weight of the storage device at a certain power-level during the time of operation. The diesel's energy density is higher by a factor 50-100 than those of accumulators. Therefore it is assumed that agricultural devices will still be powered by an internal combustion engine in the future.

TABLE I
COMPARISON OF ENERGY SOURCES / STORAGE SYSTEMS [1] – [3]

Storage system / Source of energy	Specific Energy (Wh/kg)	Specific Power (W/kg)
Lead-acid battery Pb/PbO2	32 … 40	200 … 430
Nickel metal hydride NiMH	43 … 90	140 … 1,300
Li-Ion	100 … 200	200 … 500
SuperCaps	2.5	1,750 … 4,700
Petrol	12,700	n.a.
Diesel	11,800	n.a.

The specific power indicates how quickly a storage device can be charged or discharged. If the brake-energy shall be utilized, than the present kinetic energy must be transferred into the storage within a tight period of time. Capacitive systems (e.g. Supercaps) are preferably used in such applications.

II. AGRICULTURAL MACHINERY WITH ELECTRIC DRIVES

In 2007 John Deere presented their e-Premium tractor. It was basically a standard tractor with an additional 20 kW generator. At the same time Rauch powered its spreader Axis EDR by this JD-tractor in a pioneer project. Amazone-Werke presented the potential of electric drives on a sprayer and Pöttinger built a mock-up of an electric driven rake. Many more examples can be found in literature [4]-[9].

It is obvious that the presented machines and implements with electric power-drive are mainly pure electrified or in serial hybrid-structure.

In those system-architectures, first the whole power delivered by the diesel-engine is transformed into electric power by a generator and, second, re-transformed into

Manuscript received October 18, 2013. This work is part of the project Future Farm Technology (FFT) and was supported in part by the COMET programme of the Austrian Research Promotion Agency

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DOI: 10.5176/0000-0000_1.1.4

mechanical movement by an electric motor. Control-units and, if necessary, storage devices are installed between. The amount of transformed power has to be considered carefully with respect to the losses that occur during transformation. For certain applications power-split or parallel hybrid-structures are useful, as described e.g. in [10], [11] (Fig. 1).

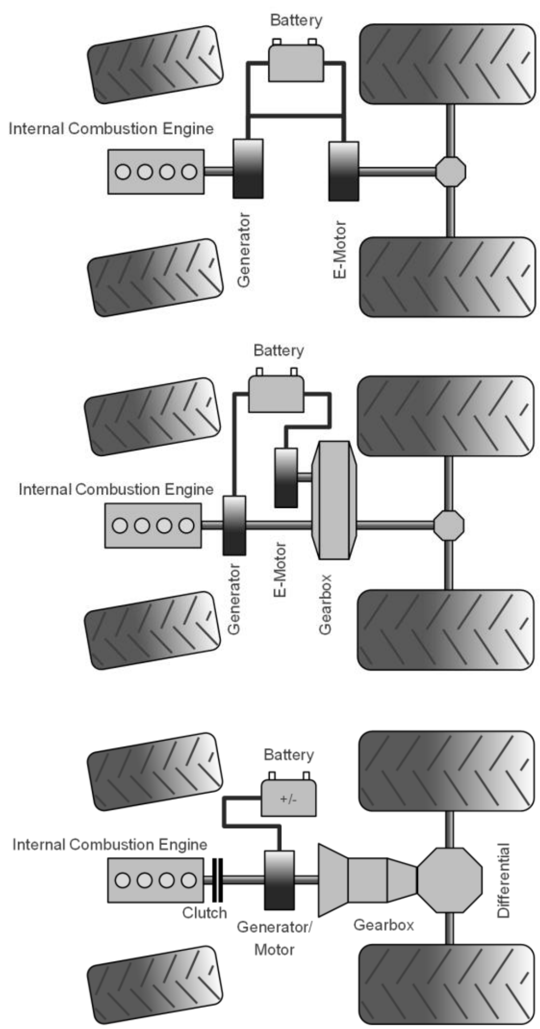

Fig. 1. Possible serial-, power-split- and parallel-hybrid structure on a tractor

Research and development in the automotive-sector does focus to the traction drive-train, basically. Agricultural machines have furthermore a huge variety of functional drives. For instance a tractor equipped with a generator could realize the functions illustrated in Fig. 2.

The specific fuel consumption of a diesel-engine in part-load operation is relatively high. When the engine operates with torque reserves, these reserves can be used to power a generator. For this purpose a battery-management-system is mandatory [2]. The advantage gained by the reduction of the specific fuel-consumption must overcome the losses raised by the energy-transformation. At vehicle stop the internal combustion engine (ICE) could be turned off, if the operating temperatures of the coolant, exhaust gases treatment system etc. have been reached. A pure electric traction drive might be beneficial for urban transportation or for short cycle

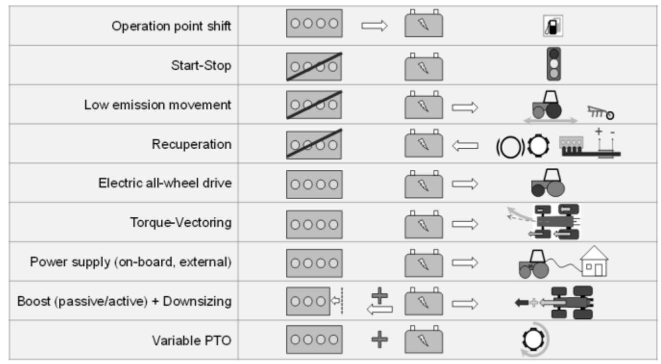

Fig. 2. Potential functions on a hybrid tractor

movements; hence the exhaust emissions and the noise exposure can be reduced. The potential for recuperation is limited in agricultural machinery [11]. In reference to the construction site machinery [11] the rotating machine parts on implements or alternating hydrostatic loads can be used for energy recovery (implement powertrain, PTO-shaft, cylinders). For small electric loads the utilization of exhaust-gas thermal energy can be considered. The tractor's front axle can be driven electrically. In this case the power distribution and the front axle-construction could be simplified. The mechanical differential can be replaced by the electric driven front wheels. The lead can be eliminated by the individual speed of each single tire with respect to the steering angle and further parameters. Advantages can be derived from [12]. Then the wheels need to be individually controlled [13]. With a variable or partly variable PTO, the working speed on rigid coupled implement-drives can be controlled independently from the speed of the internal combustion engine (ICE).

III. AGRO-HYBRID ARCHITECTURES

In general the following structures can be appropriate for functional- or traction-drives on agricultural systems (self propelled machine or tractor-implement-system):

- electrification (without second storage)
- serial agro-hybrid
- power-split agro-hybrid
- parallel agro-hybrid

Self propelled machines and tractor-implement combinations have to be distinguished. Self propelled machines are basically closed systems with functional assemblies as harvester headers or combines' cutterbars, being seldom changed in normal operation. The interface-problems are therefore solved relatively simple.

Hereinafter a tractor and a self loading wagon with variable scraper floor drive are considered as an example (Fig. 3).

The pick-up collects the windrow and the rotary loading system transfers the hay or grass by means of conveyor combs into the loading volume. If necessary, the scraper floor drive is activated to prevent congestion during loading and for the unloading operation.

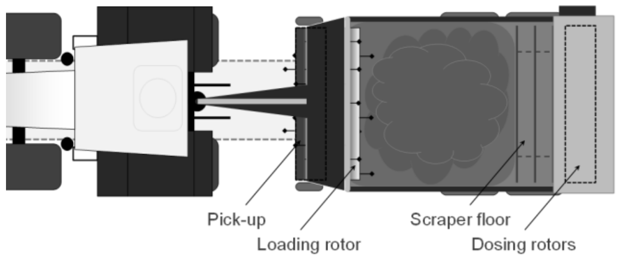

Fig. 3. Tractor with self loading wagon

The functions that could be realized by electric chain-feed drive are depending on the agro-hybrid-structure.

For a fully variable scraper floor drive including the option to reverse the direction of rotation (-n…0…+n), the serial structure is preferred (Fig. 4, a). The feed power is provided electrically, which requires a multiple transformation of the whole power needed for the feed drive. It can be generated onboard of the tractor, on an attached PTO-driven power pack system or on the implement itself [9]. The electric power can be used to power other elements, as the loader wagon's wheels (Fig. 4, b). As long as standardization of the interface definitions is not completed, the latter variant with the generator located on the loader wagon might be preferred to prevent interface conflicts.

Power-split systems can be beneficial for applications that need variable rotational speed within a certain range. The range-variability (n±Δn) can be realized by speed super-position with planetary gears. The major power is transferred conventionally e.g. by mechanical PTO-shaft. An electric motor overlaps the provided power from the PTO and covers the variable power demand (Fig. 4, c). Based on the limited range of speed-variability the amount of variable electric power is smaller than in the serial structure. Losses due to power conversion can be reduced. The superposition can be realized by hydraulics, alternatively

If power-peaks shall be covered then the use of a parallel structure (power addition) could be considered (Fig. 4, d). Power boost is possible by the electric drives (P+ΔP).

A support for acceleration of machine parts is feasible. For power boost also hydraulic elements are available [14] – [16].

The hybridization can be applied on following drives, e.g.:

- scraper floor drive
- pick-up drive
- loading rotor
- traction drive

Table II shows that the hybrid-structure and the corresponding electric power requirements depend on the requested functionality.

a) Serial structure with generator on tractor:

b) Serial structure with generator on loader wagon:

c) Power-split structure:

d) Parallel structure:

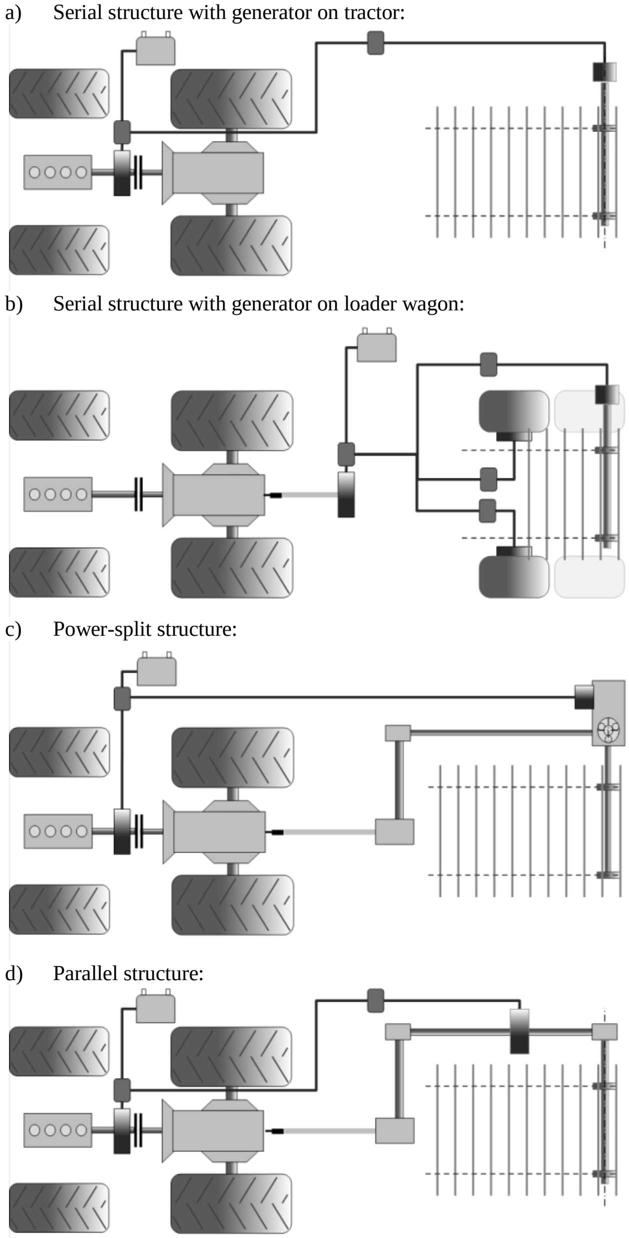

Fig. 4. Agro-hybrid structures on a scraper floor transmission

TABLE II
EXAMPLES OF REQUESTED FUNCTIONS AND AGRO-HYBRID STRUCTURES

Function	Serial agro-hybrid	Power-split agro-hybrid	Parallel agro-hybrid
fully variable scraper floor drive	x	-	-
reverse direction of scraper floor	x	(x)	-
partly variable scraper floor drive	x	x	-
reverse direction of loading rotor	x	(x)	-
boost function / dynamic load compensation	(x)	(x)	x

The thermal loads resulting from the losses during repeated power-transformation play an important role and have to be considered in the machine conception [17] – [18]. They can be kept small, e.g. with minor power, to possibly skip a separate cooling-system and utilize air-cooling only.

IV. POTENTIAL OF ELECTRIC DRIVES IN AGRICULTURAL MACHINERY

Possible applications and their power requirements were collected in two surveys among manufacturers of agricultural machinery [19], [20]. It was assessed that power values of drives on implements are typically up to 50-60 kW. The use appears to be promising in applications where infinitely variable hydrostatic drives can be replaced by electric ones (e.g. at traction drives on large self-propelled harvesters) or where processes can be automated to increase the productivity.

In total 28 drives on agricultural machines were identified of being suitable for beneficial electrification. Currently 45 % of them are hydraulic driven and 55 % mechanic. The nominal rotational speed and nominal mean power is (Table III):

TABLE III
NOMINAL SPEED AND NOMINAL POWER OF ACTUAL/SUITABLE AGRICULTURAL DRIVES [20]

Nominal speed		Nominal power	
0 … 300 rpm	30 %	0 … 10 kW	37 %
300 … 1,000 rpm	33 %	10 … 50 kW	44 %
> 1,000 rpm	37 %	50 … 100 kW	19 %

Therefore no typical range of speed can be identified. Most of actual drives (>80 %) can be covered with power up to 50 kW. This figures match with the value mentioned above.

Some 47 % would introduce e-drives due to efficiency-reasons, 53 % due to increased functionality. The availability of electric power delivered by the tractor is expected in the next 5 to 10 years. A total substitution of hydraulic or mechanic drives by electric ones is not expected [20].

The identification of beneficial applications has to be considered carefully with respect to customer acceptance.

V. CONCLUSION

The benefits of electric drives have been demonstrated in many projects. The diesel-fuel will remain as the primary energy source arising from its high energy density. The electricity will be generated by a diesel-driven electric machine. Electric drives will become more important due to the increase of efficiency and functional/productivity extension. The broad introduction of electric driven agricultural machinery is expected in the next 5 to 10 years.

The structure of the drivetrain depends on the required functionality. Serial, power-split or parallel systems favor different functions, as shown. System architectures with small variable (electric or hydraulic) power-share might be beneficial when focusing on little thermal losses.

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